sulphur. The light shed by it was pulsating and sufficiently powerful to light up the Tennessee shore and the sand bars, so as to show every log and stump."

PROBABLE INFERENCES.

1. The number of stone-falls and detonating meteors observed on the 11th, 12th, and 13th of November is more than double the average daily fall. Hence the periodic return of a cluster whose orbit intersects that of the earth is rendered highly probable.

2. None of the aerolites or meteors of the preceding list are known to have been conformable to the radiant in Leo, while those of November 13th, 1835 and November 12th, 1877, were certainly *un*-conformable; their heliocentric motion having been direct. This aerolitic group cannot therefore be connected with the shooting stars of November 14th.

3. These facts, it must be confessed, are unfavorable to the hypothesis, formerly advocated by the writer, that "meteoric stones are but the largest masses in the nebulous rings from which showers of shooting stars are derived."* It is true that in the great star showers of 1799, 1833 and 1866 a number of large fire-balls were seen which belonged undoubtedly to the cluster of Leonids; but it is remarkable that among all this number no detonation was ever heard, and that no meteoric stones have ever fallen during these extraordinary star showers.

4. The dates of the phenomena given above indicate a period of seven years. Several sporadic fire-balls, however, have appeared at this epoch, and no definite conclusion in regard to the period is possible without additional data.

Criteria of the Nebular Hypothesis.

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The views of astronomers, respecting the mode of action in world-building, have been various and vague. No one appears to have put upon record any numerical calculations, undertaken with a view crucially to test the nebular hypothesis, or any suggestions as to the proper way to make such calculations.

Statements have been made, at different times, by investigators who thought that observed velocities might be explained by the results of nebular condensation, but no one, except Ennis,† has given us any means of judging on what grounds the belief rested. It seems probable that they all regarded the formation of planetary rings as confined to the superficial

* Meteoric Astronomy, p. 64.

† "Origin of the Stars;" L., E. & D. Phil. Mag. April, 1877.

nebular layers ; that their studies were limited to the direct action of living forces ; that they used no adequate criteria for distinguishing between nebular and meteoric influences ; and that their methods often, if not always, virtually assumed the very principles which they sought to prove.

Herschel,* somewhat obscurely, intimated the possibility that nuclei might be simultaneously formed, at different points within the body of the nebula, by the action of particles of different densities. Peirce, Alexander, Hill, Wright, Kirkwood, and myself, discovered various planetary harmonies which point, unmistakably, to such synchronous internal and external activities. Yet no one seems to have thought of the likelihood that interior portions could acquire a greater angular velocity than the nebular surface, so that a planet might revolve in less time than its Sun rotated, or a satellite in less time than its primary, until I called attention to the fact that the time of nucleal rotation must vary as the $\frac{1}{3}$ power of the time of superficial nebular revolution.

The significance of this relation does not seem, even now, to be generally understood. For, when Professor Hall found that the inner satellite of Mars actually revolved with such unprecedented rapidity, Kirkwood asked, in the *American Journal of Science and Art*, "How is this remarkable fact to be reconciled with the cosmogony of Laplace?" The same question has been asked by others, and variously answered. It may, therefore, be a fitting time to state, more explicitly, some obvious evidences of present nebular activity, such as are shown in the following comparative synopsis :

M ÷	n	n^2	$n^3 = \sigma_2 = 3\,♀_2$
π	$\pi n = 2\Psi_3$	$\pi n^2 = \mathcal{U}_3 = 2\,(10)$	
π^2	$\pi^2 n = \circledcirc_3 = 2\,♄_3$	$\pi^2 n^2 = \sigma_4$	
π^4	$\pi^4 n = 2\oplus_2$	$\pi^4 n^2 = \odot\,\rho_0$	
$\pi^7 = ♀_3 = 2\,☿_3$			

M = modulus of light at Sun's surface = 2204.95 × Earth's mean radius-vector, a quantity of which I have already shown the importance ; (1) by identifying the velocity of light with the limiting velocity toward which the mean solar centrifugal and centripetal forces both tend ; (2) by showing that the same harmonic progression is manifested in the Fraunhofer lines and in planetary distances ; (3) by tracing numerous harmonic ar-

* Outlines of Astronomy, §§ 871-2.

rangements among spectral lines of chemical elements. M is the common dividend; the combinations of various powers of π and n are divisors.

π = ratio of circumference to diameter, and, as I have also shown, ratio between incipient and complete centrifugal dissociative force.

n = Gummere's criterion = $11.6569 = \frac{2}{3-2\sqrt{2}}$.* I give it this designation, because I obtained it from a calculation which was suggested by a criticism of Samuel J. Gummere, late President of Haverford College, on Ennis's theory. The criticism, together with Ennis's rejoinder, may be found in Appendix II, to "Origin of the Stars." Gummere says, of the relation $1 : \sqrt{2}$; "This relation being essential to stability, must exist, whatever be the origin of the velocity. Hence it proves nothing as to the source of the orbital velocity, except that it is entirely *compatible* with the assumption that it is due to *gravity*." This cautiousness of statement is like that which has enabled Herschel's presentation of the nebular hypothesis to adapt itself to all the astronomical discoveries which have hitherto been made.

ρ_0 = Sun's present nebular radius, or the distance at which planetary revolution and solar rotation would be synchronous.

The subscript figures denote apsidal positions: 1, secular perihelion; 2, mean perihelion; 3, mean; 4, mean aphelion; 5, secular aphelion.

The multiple, 2, denotes the primitive nebular radius which would give the *vis viva* of circular-orbital revolution, by simple condensation to the present planetary radius vector.

It should be noted that critical positions of all the planets, together with some asteroidal positions, are represented in the table; that all the symmetrical combinations of π and n, which are embraced in the table, have planetary representatives; that both rupturing factors seem to have been simultaneously operative; that, after the first conversion of linear into circular motion, the exponential increments of π are figurate; and that the relations have all been found, not by happy guessing, but by following indications which are mathematically deducible from the necessary action of central forces.

The following table shows the character of the accordances:

	Theoretical.	Observed.		Minimum Error.	Maximum Error.
$M \div \pi n$	60.210	$2\Psi_3$	60.668	+ .142	+ .142
$M \div \pi^2 n$	19.165	$\odot_3$	19.184	— .019	— .019
		$2\,\mathrm{h}_3$	19.078	+ .087	+ .087
$M \div \pi n^2$	5.165	$\mathcal{V}_3$	5.203	— .038	— .038
		$2\,\oplus_1$	5.168	— .003	— .003
$M \div \pi^2 n^2$	1.644	σ_4	1.644	.000	+ .120
$M \div \pi^4 n$	1.942	$2\oplus_2$	1.932	+ .010	— .058
$M \div n^3$	1.392	σ_2	1.403	— .011	— 132
		$2\,\mathrm{Q}_2$	1.396	— .004	— .054
$M \div \pi^7$	.730	Q_3	.723	+ .007	+ .0)7
		$2\,\mathrm{Y}_3$	.774	— .044	— .0 44
$M \div \pi^4 n^2$	.167	$\odot_\rho$	.167	.000	.000

*See *ante*, p. 99.

Gummere's criterion gives the following results of internal rupture, starting from the theoretical origin of Neptune's present orbital *vis viva*. In each instance, the theoretical angular velocity of revolution, for the dense inner planet, must have been $(11.6569)^{\frac{3}{2}}$ times as great as the angular velocity of the undisturbed portions of the gasiform rotating nebula:

	Theoretical.	Observed.
$2\Psi_4 \div n$	5.204	$\mathcal{U}_3$ 5.203
$\Psi_3 \div n$	2.576	♅ 2.577
$\odot_4 \div n$	1.760	σ_5 1.736
$\odot_3 \div n$	1.646	σ_4 1.644
$2\,\mathrm{h}_3 \div n$	1.637	
$^{\flat}2\,\mathcal{U}_4 \div n$	.931	$\oplus_1$ .932
$\mathrm{h}_2 \div n$	.779	φ_5 .774
$\mathrm{h}_1 \div n$	.749	φ_4 .749
$\mathcal{U}_5 \div n$	.473	h_5 .477
$\mathcal{U}_3 \div n$	.446	h_4 .455

The great density of Jupiter, as compared with Neptune; the great density of the intra-asteroidal, as compared with the extra-asteroidal planets; the position of Earth, in the centre of the belt of greatest planetary condensation; the connection (n) between the positions of Jupiter's incipient and Earth's complete condensation; the fact that Jupiter is the largest extra-asteroidal, while Earth is the largest intra-asteroidal planet; the further evidence of an intimate connection between Jupiter and Earth, which is furnished by the equivalence of their dissociative velocities; the probability, so far as we can judge from Sun's present nebular radius (ρ_0), that all the planets were formed when their orbital revolution was accomplished in less time than the rotation of the solar nucleus; all point to the increments of wave velocity and of centripetal velocity as a source of interior nebular rupture, giving a new meaning to Herschel's doctrine of "subsidence," and making the inner moon of Mars a confirmation, rather than a formidable objection, to the nebular hypothesis.

The tendency to synchronous oscillations under the action of central forces, which LaPlace, Peirce, and Kirkwood have so happily adduced in explanation of some of their planetary harmonies, is shown (1) in the synchronism of solar rotation with the time of passage of a light-wave through the major-axis of the Modulus-atmosphere; (2) in the synchronism of planetary revolution at Sun with the time of passage of a light-wave through the major-axis of the Uranus-Earth ellipse: Earth being the centre of the belt of greatest condensation, and Uranus having a radius-vector which is a mean proportional between M and ρ_0, as well as between $\frac{\mathrm{M}}{n}$ and $2 \oplus_2$.

For readers who are inclined to test numerical coincidences by the calculus of probabilities, I have marked the errors, in the general table, both by their deviations from the nearest apsis and by the deviations from the

semi-axis major. The importance of my introduction of various apsides into the study of planetary harmonies, has been fully recognized by Alexander, the Nestor of harmonic astronomy; but in order to avoid all possible cavil, I assume the probability that each quotient of M by $\pi^{\alpha}{}_{n'}{}^{\beta}$ is of the form $p \pm (r \text{ or less}) = \frac{2r+1}{p}$; r being the maximum tabular error, and the unit of comparison being .001 of Earth's semi-axis major. This gives a probability of more than $26(10)^{19}$ to 1 in favor of the assumed laws of planetary formation, a probability which is immeasurably increased by a consideration of the various phyllotactic, teleologic, oscillatory, elastic, centrifugal, and centripetal influences, which have been pointed out.

The three cardinal planetary centres, viz.: the centre of greatest annular condensation, (⊕); the centre of planetary inertia, (♄); and the centre of incipient solar specialization, (Ψ); lend interest to the following table:

$r \div r_0$	$\rho \div \rho_0$	ρ	O.	E.
2^3	2^4	$2.667r_1$	$2.667 = \frac{8}{3}\oplus$	.000
			$2.637 = 2^{\frac{8}{5}}\oplus_1$	.011
			$2.614 = \Psi_5 \div n$	.020
			$2.780 = \text{♄}_1 \div \pi$	.043
3^3	3^4	$13.500r_1$	$13.490 = 2^{\frac{1}{2}}\,\text{♄}_3$	.001
4^3	4^4	$42.667r_1$	$42.474 = 2^{\frac{1}{2}}\,\Psi_3$	.005
$214.86 = r_1$	$214.86^{\frac{4}{3}}$	$46083.4r_0$	$46164.7 = 214.86^2$	.002
2049.51	$2049.51^{\frac{4}{3}}$	$932262r_0$	$947511 = 2\text{M}$	.016
6453.06	$6453.06^{\frac{4}{3}}$	$4302218r_0$	$4263801 = 9\text{M} = [*] \div n$	.009

This table represents theoretical stages of nebular condensation, based upon forces which are now operating within the solar system. r_0 = present solar nucleal radius; r = past nucleal radius; r_1 = Earth's semi-axis major; ρ_0 = present nebular radius; ρ = past nebular radius; O = observed positions; E = ratio of error, found by dividing the difference between O and ρ, by ρ; $[*]$ = stellar distance, with parallax 0.″89, which is of the same order as the distance of *α Centauri*; the last three numbers in the left hand column represent, respectively, the semi-axes major of Earth, Saturn, and Neptune.

It is further worthy of note, that Earth's position is a mean proportional between the nebular radius when Sun's nucleus reached the Earth, and Sun's present surface; that the nebular radius of the Jupiter-nucleal Sun was nearly M, (.89 M); that the nebular radius of the Uranus-nucleal Sun was nearly 5 M, (4.996 M); and that M, when Sun was expanded to the outer portions of the asteroidal belt, was coincident with $[*]$, the origin of the incipient condensation of the nebular radius of the Neptune-nucleal Sun.